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ABSTRACT

Five central scientific issues are critical to consideration of the treatment in school curricula of the origin and evolution of the universe and of life on earth. These issues are: (1) the nature of science; (2) scientific evidence on the origin of the universe and the earth; (3) the consistent and validated scientific evidence for biological evolution, specifically, evidence for change over vast realms of time and for relation by common decent, evidence from molecular biology for degree of relationship, and evidence showing mechanisms of evolution; (4) human evolution; and (5) the origin of life. Discussions and conclusions concerning each of these issues are provided in this document and present the basis for the National Academy of Sciences' position that the teaching of creationism is not an appropriate activity in public schools. (JN)

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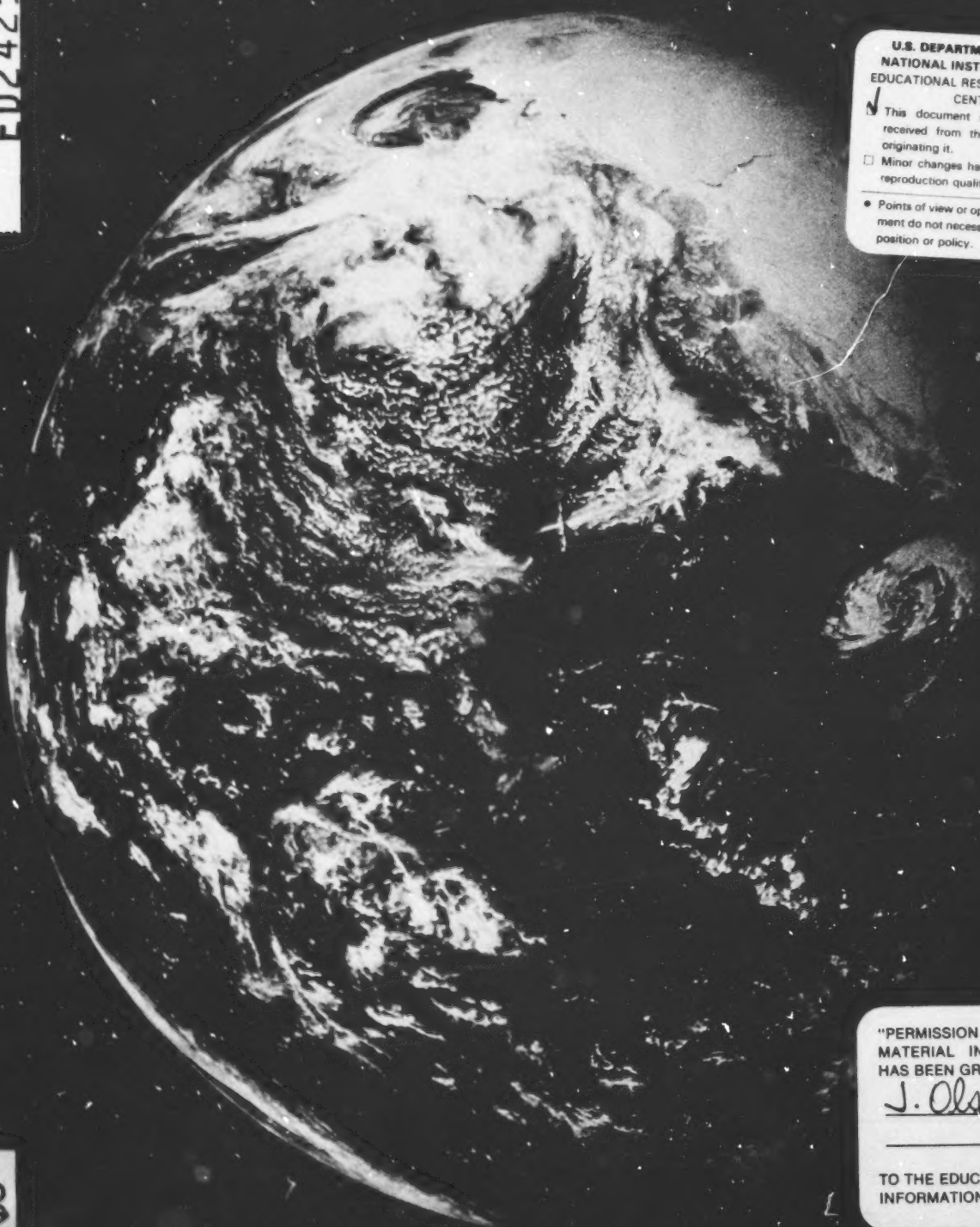
SCIENCE AND CREATIONISM

A View from the National Academy of Sciences



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SCIENCE AND CREATIONISM

A View from the National Academy of Sciences

Committee on Science and Creationism
National Academy of Sciences

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Front Cover: The United States and other parts of North America can be seen in this photograph of the earth taken by the Apollo 16 astronauts during their voyage to the moon in 1972.

Back Cover: Map of the world by Isidore of Seville (A.D. 560–636), redrawn and published in 1898 in *Mappaemundi: Die ältesten Weltkarten*—a six-volume work compiled by Konrad Miller.

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Preface

Before you begin to read this discussion of science and creationism, please take a careful look at the front and back covers of this booklet. The front cover depicts the world as we know it to be today. The back cover illustrates the world as people believed it to be in the days before Columbus sailed to the New World. Both views have a place in our lives—but one belongs in the world as we have come to know it and one belongs in history. Both views, by the way, are the products of science. How then can the two views be so different? The answer lies at the very heart of the nature of this system of study we call "science."

In science, everything we observe, measure, or discover must be successfully tested again and again before it is accepted as valid and as factual evidence of what is real. During the application of this scientific method, scientists review their data carefully—and with a healthy skepticism. Most important, the scientific method requires that the fact-seekers remain open-minded, are willing to submit their theories to rational examination, and are willing to accept changes indicated by the signposts of evidence. It is easy to see how this approach encourages the acceptance of change, which in turn fosters original thought, new ideas, and new hypotheses, all converging on a better understanding of nature.

One might think of Columbus's voyage to the New World as a test of the hypothesis that India, which lay to the east, could be reached by sailing westward on a round world. As a result of his exploration and many subsequent observations, including those from voyages into space, we now know that our world actually looks as it is shown on the front cover of this booklet.

And that is why scientists, such as those of the Council of the National Academy of Sciences who asked that this booklet be prepared, feel that teaching the scientific theory of evolution alongside creationism is inappropriate. Teaching creationism is like asking our children to believe on faith, without recourse to time-tested evidence, that the dimensions of the world are the same as those depicted in maps drawn in the days before Columbus set sail with his three small ships, when we *know* from factual observations that they are really quite different.

It is false, however, to think that the theory of evolution represents an irreconcilable conflict between religion and science. A great many religious

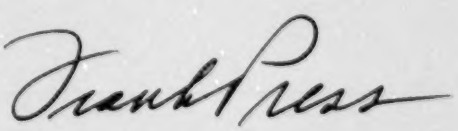
leaders and scientists accept evolution on scientific grounds without relinquishing their belief in religious principles. As stated in a resolution by the Council of the National Academy of Sciences in 1981, however, "Religion and science are separate and mutually exclusive realms of human thought whose presentation in the same context leads to misunderstanding of both scientific theory and religious belief."

The theory of evolution has successfully withstood the tests of science many, many times. Thousands of geologists, paleontologists, biologists, chemists, and physicists have gathered evidence in support of evolution as a fundamental process of nature. Our understanding of evolution has been refined over the years, and indeed its details are still undergoing testing and evaluation. For example, some scientists currently debate competing ideas about the rate at which evolution occurred. One group believes that evolution proceeded in small, progressive stages evenly spread throughout the billions of years of geological time; another group believes that there were alternating periods of relatively rapid and slow changes throughout time.

Creationists sometimes cite this debate as evidence for disagreement about evolution among scientists; some even suggest that scientists who advocate the latter hypothesis are actually supporting a process similar to that of creationism. What these creationists fail to understand, however, is that neither scientific school of evolutionary thought questions the scientific evidence that evolution took place over billions of years. Rather, the debate centers on only the finer details of *how* it took place.

Debate among scientists is expected. And the products of such debate over the years have been truly astonishing. Scientific debate influenced the planning of Columbus's voyage and, more recently, the explorations of space. But debate does not mean resurrecting old theories that have long been invalidated by observations and experiments. Theories that are supported by evidence, and which survive the rigorous testing of the scientific method, are passed on to future generations. Examples are the germ theory of disease; the theory of gravity, which controls the movement of planets; and the theory of evolution. Those that are discounted by the evidence, and which fail by the scientific method, are of interest only to the historians of science.

In a nation whose people depend on scientific progress for their health, economic gains, and national security, it is of utmost importance that our students understand science as a system of study, so that by building on past achievements they can maintain the pace of scientific progress and ensure the continued emergence of results that can benefit mankind.



Frank Press
President
National Academy of Sciences

Science and Creationism: A View from the National Academy of Sciences

State legislatures are considering, and some have passed, bills that would require the introduction of biblical creationism in science classes wherever evidence for the origin of the planet, of life and its diverse forms, or of mankind is presented. Local school boards have passed ordinances intended to restrict the teaching of biological concepts of evolution or to require what is called a "balanced treatment" of creationism and evolution. Publishers of science textbooks are under pressure to deemphasize accepted scientific theories of evolution while adding course material on "creation science."

The teachings of creationism as advocated by and exemplified in the writings of the leading proponents of "creation science" include the following judgments: (1) the earth and universe are relatively young, perhaps only 6,000 to 10,000 years old; (2) the present physical form of the earth can be explained by "catastrophism," including a worldwide flood; and (3) all living things (including humans) were created miraculously, essentially in the forms we now find them. These teachings may be recognized as having been derived from the accounts of origins in the first two chapters of Genesis in the Bible.

Generations of able and often devout scientists before us have sought evidence for these teachings without success. Foremost among these was Charles Darwin, a member in good standing of the Church of England and an officer of his parish church at Down, in Kent, for many years. His search more than a century ago gave us instead a hypothesis for the origin of species by means of natural selection. Others have given us hypotheses about the origin and history of the earth and the universe itself. These hypotheses have been tested and validated by many different lines of inquiry. With modifications to include new findings, they have become the central organizing theories that make the universe as a whole intelligible, lend coherence to all of science, and provide fruitful direction to modern research. The hypothesis of special creation has, over nearly two centuries, been repeatedly and sympathetically considered and rejected on evidential grounds by qualified observers and experimentalists. In the forms given in the first two chapters of Genesis, it is now an invalidated hypothesis. To reintroduce it into the public schools at this time as an element of science teaching would be akin to requiring the teaching of Ptolemaic astronomy or pre-Columbian geography.

Confronted by this challenge to the integrity and effectiveness of our national education system and to the hard-won evidence-based foundations of science, the National Academy of Sciences cannot remain silent. To do so would be a dereliction of our responsibility to academic and intellectual freedom and to the fundamental principles of scientific thought. As a historic representative of the scientific profession and designated advisor to the Federal Government in matters of science, the Academy states unequivocally that the tenets of "creation science" are not supported by scientific evidence, that creationism has no place in a *science* curriculum at any level, that its proposed teaching would be impossible

in any constructive sense for well-informed and conscientious science teachers, and that its teaching would be contrary to the nation's need for a scientifically literate citizenry and for a large, well-informed pool of scientific and technical personnel.

The Central Scientific Issues Five central scientific issues are critical to consideration of the treatment in school curricula of the origin and evolution of the universe and of life on earth:

- the nature of science;
- scientific evidence on the origin of the universe and the earth;
- the consistent and validated scientific evidence for biological evolution: specifically, evidence for change over vast realms of time and for relation by common descent, evidence from molecular biology for degree of relationship, and evidence showing mechanisms of evolution;
- human evolution; and
- the origin of life.

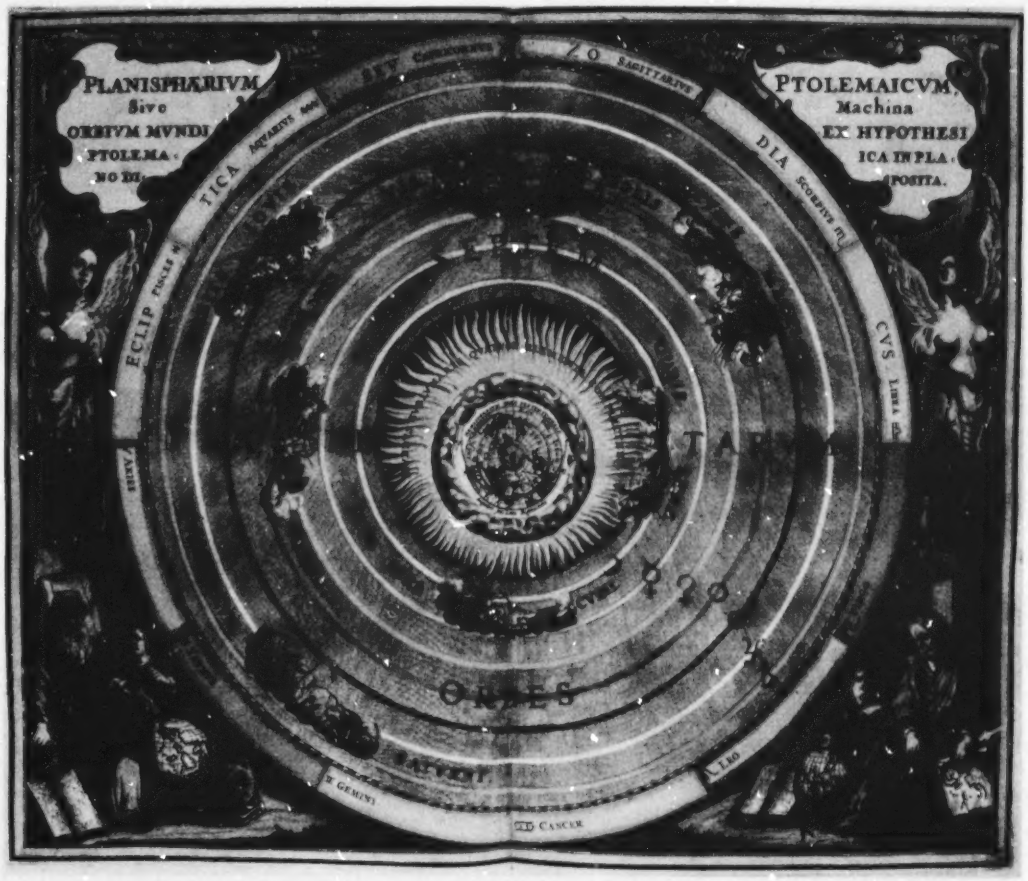
Discussions and conclusions concerning each of these issues make up the balance of this document and present the basis for the Academy's position that the teaching of creationism is not an appropriate activity in our public schools.

The Nature of Science

It is important to clarify the nature of science and to explain why creationism cannot be regarded as a scientific pursuit. The claim that equity demands balanced treatment of the two in the same classroom reflects misunderstanding of what science is and how it is conducted. Scientific investigators seek to understand natural phenomena by direct observation and experimentation. Scientific interpretations of facts are always provisional and must be testable. Statements made by any authority, revelation, or appeal to the supernatural are not germane to this process in the absence of supporting evidence. In creationism, however, both authority and revelation take precedence over evidence. The conclusions of creationism do not change, nor can they be validated when subjected to test by the methods of science. Thus, there are profound differences between the religious belief in special creation and the scientific explanations embodied in evolutionary theory. Neither benefits from the confusion that results when the two are presented as equivalent approaches in the same classroom.

In broadest terms, scientists seek a systematic organization of knowledge about the universe and its parts. This knowledge is based on explanatory principles whose verifiable consequences can be tested by independent observers. Science encompasses a large body of evidence collected by repeated observations and experiments. Although its goal is to approach true explanations as closely as possible, its investigators claim no final or permanent explanatory truths. Science changes. It evolves. Verifiable

facts always take precedence. The beautifully symmetrical and once inspiring hypothesis of an earth-centered universe, apparently supported by the "common sense" observation that the sun and stars orbit the earth, fell before an accumulation of new evidence. Today's theory of an expanding universe of 10 thousand billion billion or more stars, with all its puzzles and uncertainties, is far more consistent with the evidence now available.



The Ptolemaic System. This astronomical system was developed by Ptolemy (ca. A.D. 100–170), who postulated that the earth was the center of the universe and that the moon, planets, and stars revolved around it.

Scientists operate within a system designed for continuous testing, where corrections and new findings are announced in refereed scientific publications. The task of systematizing and extending the understanding of the universe is advanced by eliminating disproved ideas and by formulating new tests of others until one emerges as the most probable explanation for any given observed phenomenon. This is called the scientific method.

An idea that has not yet been sufficiently tested is called a hypothesis. Different hypotheses are sometimes advanced to explain the same factual evidence. Rigor in the testing of hypotheses is the heart of science. If no verifiable tests can be formulated, the idea is called an *ad hoc* hypothesis—one that is not fruitful; such hypotheses fail to stimulate research and are unlikely to advance scientific knowledge.

A fruitful hypothesis may develop into a theory after substantial observational or experimental support has accumulated. When a hypothesis has survived repeated opportunities for disproof and when competing hypotheses have been eliminated as a result of failure to produce the pre-

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Sir Isaac Newton (1642–1727) was an English mathematician and natural philosopher who formulated the laws of gravity and motion and the elements of differential calculus. He presaged our present-day satellites in a sketch (below) depicting the results that could be expected if a projectile were fired from a mountaintop at several different velocities. This first appeared after his death in *A Treatise of the System of the World*, a volume published in London in 1728. Newton had argued that a projectile launched with sufficient velocity would orbit the earth. This principle has been demonstrated many times during the twentieth century in space explorations such as the journey of the orbiter *Challenger* (right), shown during its second lift-off in June 1983.

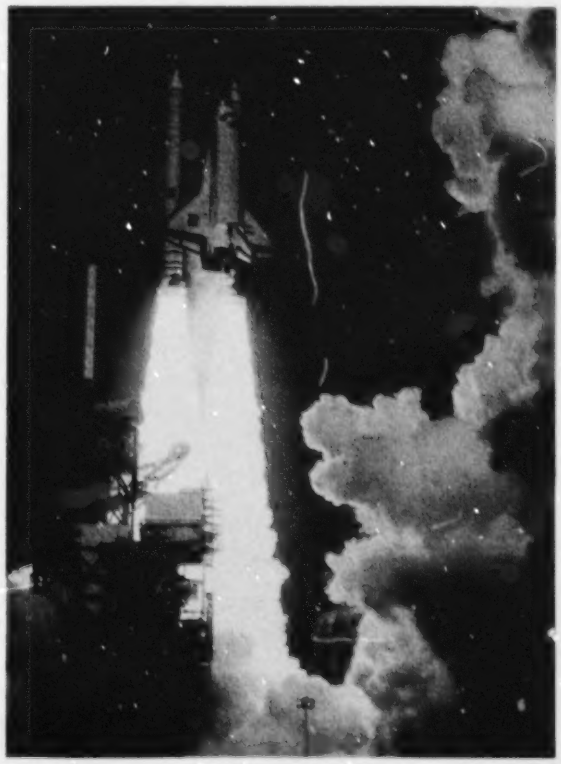
dicted consequences, that hypothesis may become the accepted theory explaining the original facts.

Scientific theories are also predictive. They allow us to anticipate yet unknown phenomena and thus to focus research on more narrowly defined areas. If the results of testing agree with predictions from a theory, the theory is provisionally corroborated. If not, it is proved false and must be either abandoned or modified to account for the inconsistency.

Scientific theories, therefore, are accepted only provisionally. It is always possible that a theory that has withstood previous testing may eventually be disproved. But as theories survive more tests, they are regarded with higher levels of confidence. A theory that has withstood as many severe tests as, for example, that of biological evolution by means of natural selection is held with a very high degree of confidence.

In science, then, facts are determined by observation or measurement of natural or experimental phenomena. A hypothesis is a proposed explanation of those facts. A theory is a hypothesis that has gained wide acceptance because it has survived rigorous investigation of its predictions.

Higher levels of generalization are formulated into scientific laws. A law identifies a class of regularities in nature from which there has been no known deviation after many observations or trials. It is usually expressed mathematically. The laws of Newtonian and relativistic motion and those of thermodynamics are examples. Scientific laws tell us the ways but not the whys of nature. They are used in launching and manipulating space probes, investigating the far reaches of the universe, mapping deep-sea topography from the surface, or probing the earth's internal structure. We must heed them in formulating new hypotheses and theories.



By the standards described above, special creation is neither a successful theory nor a testable hypothesis for the origin of the universe, the earth, or of life thereon. Creationism reverses the scientific process. It accepts as authoritative a conclusion seen as unalterable and then seeks to support that conclusion by whatever means possible.

In contrast, science accommodates, indeed welcomes, new discoveries: its theories change and its activities broaden as new facts come to light or new potentials are recognized. Examples of events changing scientific thought are legion. Here, for example, we mention four that are both recent and germane to the subject of this document.

1. The study of the origin of life as a product of chemical evolution became possible only with advances, mostly since World War II, in our understanding of early atmospheres, with the development of geochronological dating and other research methods, and with the discovery of a long sequence of mainly microbial Precambrian fossils.
2. Evidence for deciphering the earliest stages in the evolution of the solar system arrived on earth in a meteorite that fell in Sonora, Mexico, in 1969.
3. The fortuitous discovery in 1965 of a universal background radiation at a temperature of approximately −270° Celsius (3° Celsius above absolute zero) brought the first concrete evidence about the nature of the earliest universe.
4. Discoveries during the past three decades of hominoid remains in East Africa, Pakistan, and elsewhere have combined with advances in molecular biology to initiate a new subscience—paleoanthropology. This field of inquiry is providing an ever-growing inventory of evidence both for a close evolutionary connection between modern humans (*Homo sapiens sapiens*) and their australopithecine ancestors and for a clear genetic affinity between human beings and the chimpanzee.

Prior acceptance of the fixed *ad hoc* hypotheses of creationism—ideas that are certified as untestable by their most ardent advocates—would have blocked these and other important advances that have led to the great scientific achievements of recent years. Truly scientific understanding cannot be attained or even pursued effectively when explanations not derived from or tested by the scientific method are accepted.

Scientific Evidence on the Origin of the Universe and the Earth

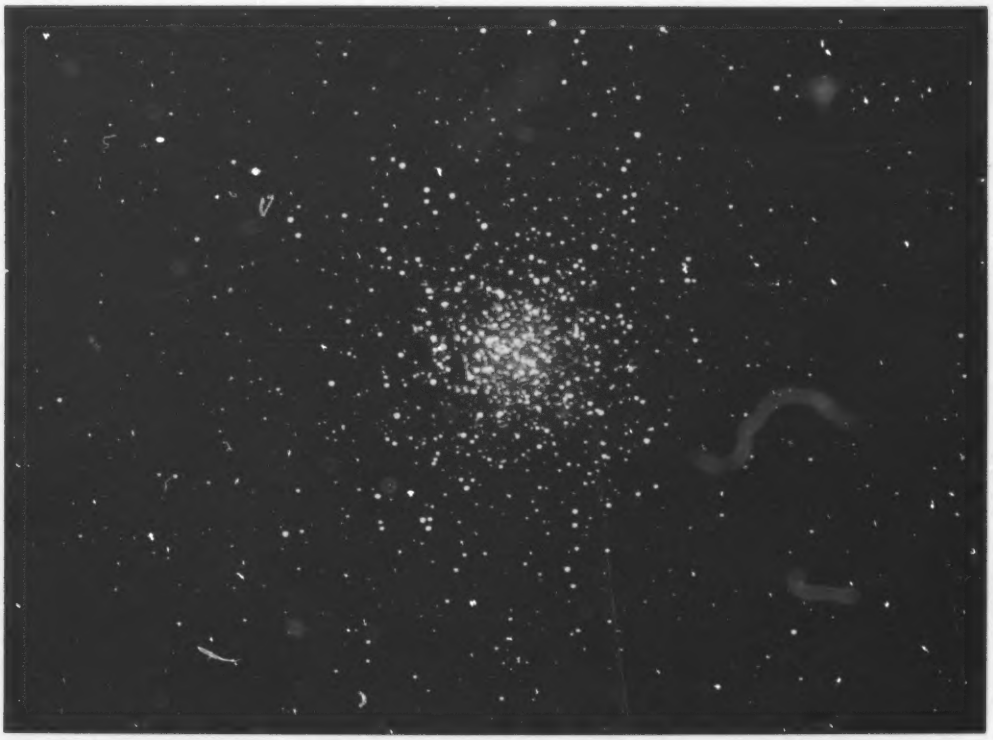
The processes by which new galaxies, stars, and our own planetary system are formed are sometimes referred to as the "evolution" of the universe, the stars, and the solar system. The word *evolution* in this context has a very different meaning than it does when applied to the evolution of organisms. In both instances there is an unfolding, but the processes involved are entirely different. The relevant sciences involved are also different—biological sciences in the evolution

Edwin Hubble (1889–1953), pictured below, accumulated a wealth of fundamental data that served as a basis for many of the theories of cosmology. "Hubble's law of the red shift" was based on his finding that extragalactic nebulae recede at velocities that increase linearly with distance. He also discovered that these nebulae were in fact isolated systems outside the Milky Way. One such system is the spiral galaxy Messier 66, shown above.

of organisms and the physical sciences in the evolution of the universe and its constituent domains.

Evidence that the evolution of the universe has taken place over at least several billion years is overwhelming. Among the most striking indications of this process are the receding velocities of distant galaxies. This general expansion of the universe was first noted in the late 1920s and early 1930s by the American astronomer Edwin Hubble from his studies of the changing wavelengths of light from distant stars and galaxies (Hubble, 1929; Hubble and Humason, 1931). Extrapolating backwards, astronomers today estimate that the expansion probably began some 10 to 20 billion years ago. This concept of expansion from a more dense early state was dramatically confirmed in 1965, when faint radio static left over from the early universe was discovered by radio astronomers at the Bell Laboratories (Penzias and Wilson, 1965). The intensity of this static was just what would be expected to result from the expansion of the universe. Confirming earlier predictions, the discovery strongly reinforced the scientific theory that the universe evolved from an initially dense state at a starting temperature of approximately 100 billion degrees Celsius (Weinberg, 1977).

The invariant spontaneous decay of the radioactive isotopes of some elements, resulting in the formation of inert daughter isotopes of other elements, provides further evidence that the universe is billions of years old. Analyses of the relative abundances of radioactive isotopes and their inert decay products in the earth, meteorites, and moon rocks all lead to the conclusion that these bodies are about 4.5 billion years old. This finding agrees with calculations of the age of the sun based on the theory of stellar evolution and is consistent with estimates of the time that would be required for the origin of life and the evolution of organisms. Another



Large clusters of stars, such as the "globular cluster" in the constellation Hercules (above), provide direct observational evidence of stellar evolution.

measure of age comes from the relative abundance of uranium isotopes. The relative rarity of the isotope uranium-235, whose half-life is roughly 0.7 billion years, tells us that the earth's uranium is approximately 7 billion years old. We do not know how long after the beginning of the universe it took to form the uranium found on earth, but its presence and relative abundance require that the age of the universe be at least 7 billion years. Although our picture of the origin and evolution of the universe, the stars, and the earth is tentative, our reservations should not be confused with uncertainty about their great age.

Astrophysicists also have developed plausible hypotheses concerning the formation of galaxies, individual stars, and planetary systems. The sun and planets in our solar system are believed to have been formed by condensations from an interstellar cloud of dust and gas like those now visible in parts of our galaxy. New evidence from the geochemical study of isotopes in the Allende meteorite implies that the condensation resulting in our solar system was initiated by a nearby exploding star (or supernova) about 4.5 billion years ago. Many details are uncertain, but there is general agreement on the broader aspects of this process.

The evolution of stars is understood more quantitatively. Comparisons of computer simulations of stellar evolution with the observed distribution of the temperature and luminosities of stars in large clusters indicate that the clusters are typically around 10 billion years old.

A major reason for the creationists' opposition to the geological record and evolution is their belief that earth is relatively young, perhaps only a few thousand years old. In rejecting evidence for the great age of the universe, creationists are in conflict with data from astronomy, astrophysics, nuclear physics, geology, geochemistry, and geophysics. The creationists' conclusion that the earth is only a few thousand years old was

originally reached from the timing of events in the Old Testament, including the counting of recorded generations (Renckens, 1964). Recent attempts to support this conclusion include arguments that the present magnetic field of the earth is the decaying remnant of a magnetic field that was created with it and that if the earth were more than 10,000 years old the initial strength of the field would have been impossibly large. This is one creationist tenet that can be, and has been, scientifically tested but that has not withstood scrutiny. Current scientific data support the theory that the earth's magnetic field is a product of the motions of its fluid core. The field varies and shifts, but between shifts it is maintained and is constantly renewed by dynamo effects within the core.

Scientists knew that the earth was old before they knew how old. Today more than a dozen independent radiometric methods are used to measure ages in years, based on different decay systems with different decay constants and on the ratios of the decay products of different uranium isotopes. When the age of a given rock is found to be the same when measured by a variety of different isotopic systems, scientists accept that age with a high level of confidence. There is very low probability that different isotopic systems with different constants would produce the same results by chance. Suffice it to say here that the cumulative geochronological evidence indicates the ages of the earth and solar system to be about 4.5 billion years.

The Scientific Standing of Biological Evolution

Contrary to popular opinion, neither the term nor the idea of biological evolution began with Charles Darwin and his foremost work *On the Origin of Species by Means of Natural Selection* (1859). The *Oxford English Dictionary* (1933) tells us that the word *evolution*, to unfold or open out, was derived from the Latin *evolvere*, which applied to the "unrolling of a book." It first appeared in the English language in 1647 in a nonbiological connection. It became widely used in English in its primary Latin meaning for all sorts of progressions from simpler beginnings. Evolution was first used as a biological term in 1670 to describe the changes observed in the maturation of insects. However, it was not until the 1873 edition of *The Origin of Species* that Darwin first applied the term. Before that he used the expression *descent with modification*, which is still as good a brief definition of biological evolution as any. In later editions of the book, Darwin paid tribute to the earlier views of Jean Baptiste de Lamarck (1802, 1809) and others about the subject we now call biological evolution or simply evolution.

Charles Robert Darwin (1809–1882), the English naturalist who developed the theory of evolution by natural selection.

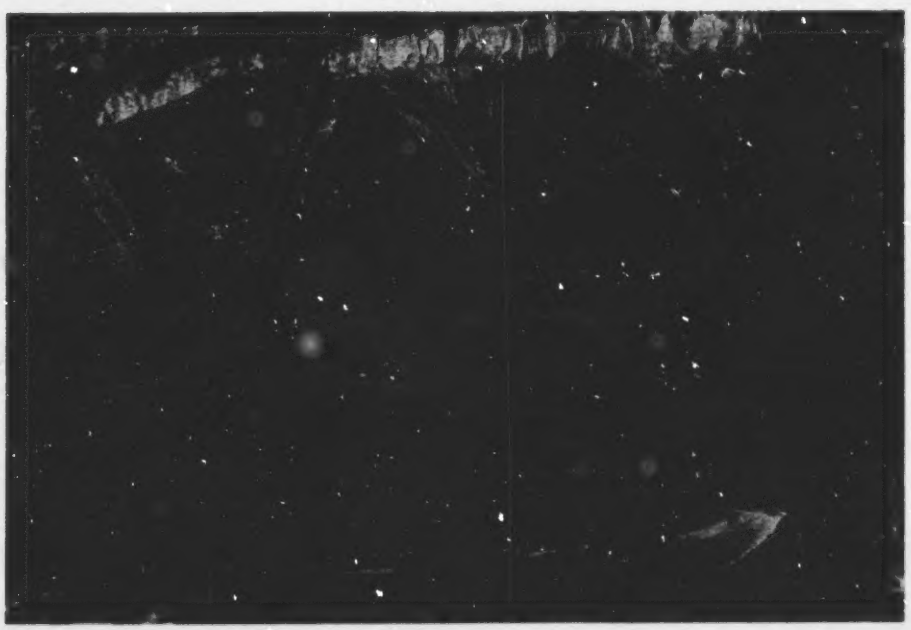
Although it was Darwin, above all others, who first marshaled the convincing critical evidence for biological evolution, earlier alert scholars recognized that the succession of living forms on the earth had changed systematically with the passage of geological time. The first recorded test of the predictive powers of the hypothesis was met in the 1830s. The paleontologist William Lonsdale recognized that fossils from geographi-

cally isolated rocks now classified as Devonian were intermediate in their degree of development between Silurian forms in deeper strata and Carboniferous ones above—a sequence that has since been independently confirmed thousands of times (Geikie, 1897; Tasch, 1950).

As applied to biology, a distinction is to be drawn between the questions (1) *whether* and (2) *how* biological evolution happened. The first refers to the finding, now supported by an overwhelming body of evidence, that descent with modification occurred during more than 2.7 billion years of earth's history. The second refers to the theory explaining how those changes developed along the observed lineages. The mechanisms are still undergoing investigation; the currently favored theory is an extensively modified version of Darwinian natural selection.

With that proviso we will now consider three aspects of biological evolution in more detail: relation by common descent, molecular biology as it explains the degree of relationship, and the mechanisms of evolution.

Relation by Common Descent Evidence for relation by common descent has been provided by paleontology, comparative anatomy, biogeography, embryology, biochemistry, molecular genetics, and other biological disciplines. The idea first emerged from observations of systematic changes in the succession of fossil remains found in a sequence of layered rocks. Such layers are now known to have a cumulative thickness of many scores of kilometers and to represent at least 2.7 billion years of geological time. The first observation that the final sequence changes systematically upward in an undeformed succession of stratified rocks (and thus with time) was announced in 1799 by a practical engineer named William Smith (Geikie, 1897). His findings were confirmed and extended by a number of paleontologists and geologists who used the fossils not as proof of evolution but as a basis for working out the original sequences of structurally disturbed rock strata.



The Grand Canyon, with the Colorado River winding through its depths, as seen from Moran Point on the south rim. The many different strata of rocks that accumulated during the succession of geological ages are clearly visible in the canyon walls.

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The general sequence of fossils had thus already been recognized when Darwin perceived that the observed progression of biological forms strongly implied common descent. The farther back into the past one looked, the less the fossils resembled recent forms, the more the various lineages merged, and the broader the implications of a common ancestry appeared.

In Darwin's time, however, paleontology was still a rudimentary science, and large parts of the geological succession of stratified rocks were unknown or inadequately studied. Darwin, therefore, worried about the rarity of truly intermediate forms. Creationists have then and now seized on this as a weakness in evolutionary theory. Indeed, although gaps in the paleontological record remain even now, many have been filled by the researches of paleontologists since Darwin's time. Hundreds of thousands of fossil organisms found in well-dated rock sequences represent a succession of forms through time and manifest many evolutionary transitions. Microbial life of the simplest type (i.e., procaryotes, which are cells whose nuclear matter is not bounded by a nuclear membrane) was already in existence 2.7 billion years ago and perhaps even earlier. The oldest evidence suggesting the existence of more complex organisms (i.e., eucaryotic cells with a true nucleus) has been discovered in fossils that had been hermetically sealed in flinty rocks approximately 1.4 billion years old. More advanced forms like true algae, fungi, higher plants, and animals have been found only in still younger geological strata. The following list presents the order in which progressively complex forms of life appeared:

Life Form	Millions of Years Since First Known Appearance (Approximate)
Microbial (procaryotic cells)	2,700
Complex (eucaryotic cells)	1,400
First multicellular animals	670
Shell-bearing animals	540
Vertebrates (simple fishes)	490
Amphibians	350
Reptiles	310
Mammals	200
Nonhuman primates	60
Earliest apes	25
Australopithecine ancestors	5
Homo sapiens sapiens (modern humans)	0.05 (50,000 years)

The sequence of observed forms and the fact that all except the first are constructed from the same basic cellular type strongly imply that all these major categories of life (including plants, true algae, and fungi) have a common ancestry in the first eucaryotic cell. Morever, there have been so many discoveries of intermediate forms between fish and amphibians, between amphibians and reptiles, between reptiles and mammals, and even along the primate line of descent that it is often difficult to identify categorically the line to which a particular genus or species belongs. Indeed, nearly all fossils can be regarded as intermediates in some sense—as life forms that come between related forms that preceded them and those that followed.

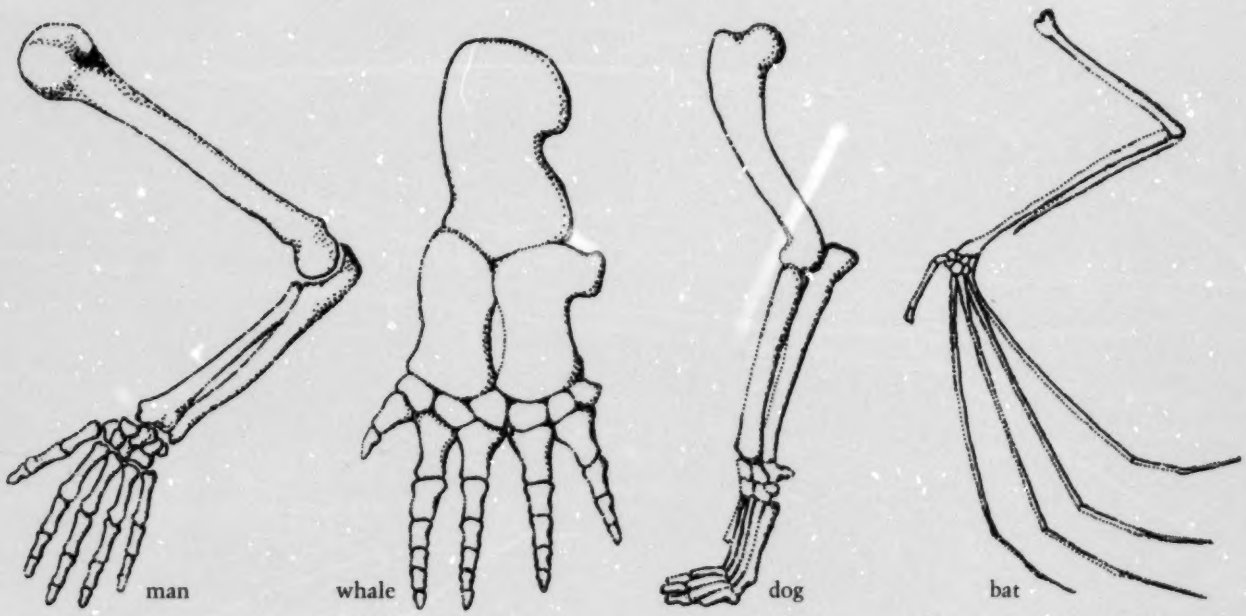
Archaeopteryx has one skeletal feature that is exclusively avian—the wishbone, or furcula (fused clavicles). All other recognizable features of its skeleton are also found in various carnivorous dinosaurs. For this reason, *Archaeopteryx* is considered by many to have been an intermediate form between dinosaurs and birds. In 1877 this specimen was found embedded in the 150-million-year-old Jurassic Solnhofen limestones of Bavaria.

The fossil record thus provides compelling evidence of systematic change through time—of descent with modification. From this consistent body of evidence it can be predicted that no reversals will be found in future paleontological studies. That is, amphibians will not appear before fishes nor mammals before reptiles, and no complex life will occur in the geological record before the oldest eucaryotic cells. That prediction has been upheld by the evidence that has accumulated thus far: no reversals have been found.

Creationists have sometimes cited an investigation of human footprints said to be associated with those of dinosaurs. These footprints were reported to have been found in a roughly 90-million-year-old layer of rock near Glen Rose, Texas. It was subsequently discovered by a young creationist himself that some of the human-looking footprints had been carved by pranksters and that the reportedly convincing ones were no longer present (Morris, 1980). There is no evidence that humans lived at the time of the dinosaurs. In fact, there is much that is opposed to that conclusion.

Although creationists claim that the entire geological record, with its orderly succession of fossils, is the product of a single universal flood that lasted a little longer than a year and covered the highest mountains to a

depth of some 7 meters a few thousand years ago, there is clear evidence in the form of intertidal and terrestrial deposits that at no recorded time in the past has the entire planet been under water. Moreover, a universal flood of sufficient magnitude to deposit the existing strata, which together are many scores of kilometers thick, would require a volume of water far greater than has ever existed on and in the earth, at least since the formation of the first known solid crust about 4 billion years ago. The belief that all this sediment with its fossils was deposited in an orderly sequence in a year's time defies all geological observations and physical principles concerning sedimentation rates and possible quantities of suspended solid matter. We do not doubt that there were periods of unusually high rainfall or that extensive flooding of inhabited areas has occurred, but there is no scientific support for the hypothesis of a universal, mountain-topping flood.



The structural similarities (homology) of the forelimbs of these vertebrates suggest a common origin.

Inferences about common descent derived from paleontology have been reinforced by comparative anatomy. The skeletons of humans, dogs, whales, and bats are strikingly similar, despite the different ways of life led by these animals and the diversity of environments in which they have flourished. The correspondence, bone by bone, can be observed in every part of the body, including the limbs. Yet a person writes, a dog runs, a whale swims, and a bat flies—with structures built of the same bones.

Scientists call such structures homologous and have concurred that they are best explained by common descent. Comparative anatomists investigate such homologies, not only in bone structure but also in other parts of the body as well, working out relationships from degrees of similarity. Their conclusions provide important inferences about the details of evolutionary history that can be tested by comparisons with the sequence of ancestral forms in the paleontological record.

The mammalian ear and jaw offer another instance in which paleontology and comparative anatomy combine to show common ancestry

through transitional stages. The lower jaws of mammals contain only one bone, whereas those of reptiles have several. The other bones in the reptile jaw are homologous with bones now found in the mammalian ear. What function could these bones have had during intermediate stages? Paleontologists have now discovered two intermediate forms of mammal-like reptiles (Therapsida) with a double jaw joint—one composed of the bones that persist in mammalian jaws, the other consisting of bones that eventually became the hammer and anvil of the mammalian ear. Similar examples are numerous. Some specific findings relating to human beings are described later in this document.

Biogeography also has contributed evidence for common descent. The diversity of life is stupendous. Approximately 250,000 species of living plants, 100,000 species of fungi, and perhaps 1.5 million additional species of animals and microorganisms have been described and named, each occupying its own peculiar ecological setting or niche, and the census is far from complete. Some species, such as human beings and our companion the dog, can live under a wide range of environmental conditions. Others are amazingly specialized. One species of the fungus *Laboulbenia* grows exclusively on the rear portion of the covering wings of a single species of beetle (*Aphaenops cronei*) found only in some caves of southern France. The larvae of the fly *Drosophila carcinophila* can develop only in specialized grooves beneath the flaps of the third pair of oral appendages of the land crab *Gecarcinus ruricola*, which is found only on certain Caribbean islands.

How can we make intelligible the colossal diversity of living beings and the existence of such extraordinary, seemingly whimsical creatures as *Laboulbenia*, *Drosophila carcinophila*, and others? Why are island groups like the Galapagos so often inhabited by forms similar to those on the nearest mainland but belonging to different species? Why is the indigenous life so different on different continents? Creationists contend that the curious facts of biogeography result from the occurrence of a special creationary event. A scientific hypothesis proposes that biological diversity results from an evolutionary process whereby the descendants of local or migrant predecessors became adapted to their diverse environments. A testable corollary of that hypothesis is that present forms and local fossils should show homologous attributes indicating how one is derived from the other. Also, there should be evidence that forms without an established local ancestry had migrated into the locality. Wherever such tests have been carried out, these conditions have been confirmed. A good example is provided by the mammalian populations of North and South America, where strikingly different endemic forms evolved in isolation until the emergence of the Isthmus of Panama approximately 3 million years ago. Thereafter, the armadillo, porcupine, and opossum—mammals of South American origin—were able to migrate to North America along with many other species of plants and animals, while the placental mountain lion and other North American species made their way across the isthmus to the south.

The evidence that Darwin found for the influence of geographical distribution on the evolution of organisms has become stronger with advancing knowledge. For example, approximately 2,000 species of flies belonging to the genus *Drosophila* are now found throughout the world. About one-quarter of them live only in Hawaii. More than a thousand

species of snails and other land mollusks are also found in Hawaii. The only natural explanation for the occurrence of such great diversity among closely similar forms is that the differences resulted from adaptive colonization of isolated environments by animals with a common ancestry. The Hawaiian islands are far from, and were never attached to, any mainland or other islands, and they have had few colonizers. Organisms that reached these islands found many unoccupied and relatively isolated ecological niches where they could then undergo separate evolutionary diversifications.

The vagaries of biogeography cannot be attributed to environmental peculiarities alone. The Hawaiian islands are no better than other Pacific islands for the survival of *Drosophila*, nor are they less hospitable than other parts of the world for many organisms not indigenous to them. For example, pigs and goats have multiplied in Hawaii after their introduction by humans. Thus, organisms are also absent from places well suited to their occupancy where potential ancestors were lacking.

Embryology, the study of biological development from the time of conception, is another source of independent evidence for common descent. Barnacles, for instance, are sedentary crustaceans with little apparent similarity to such other crustaceans as lobsters, shrimps, or copepods. Yet barnacles pass through a free-swimming larval stage, in which they look unmistakably like other crustacean larvae. The similarity of larval stages supports the conclusion that all crustaceans have homologous parts and a common ancestry. Similarly, human and other mammalian embryos pass through a stage during which they have unmistakable but useless grooves similar to gill slits found in fishes—evidence that they and the other vertebrates shared remote ancestors that respired with the aid of gills.

Finally, the substantiation of common descent that emerges from all the foregoing lines of evidence is being validated and reinforced by the discoveries of modern biochemistry and molecular biology, as discussed in the following section.

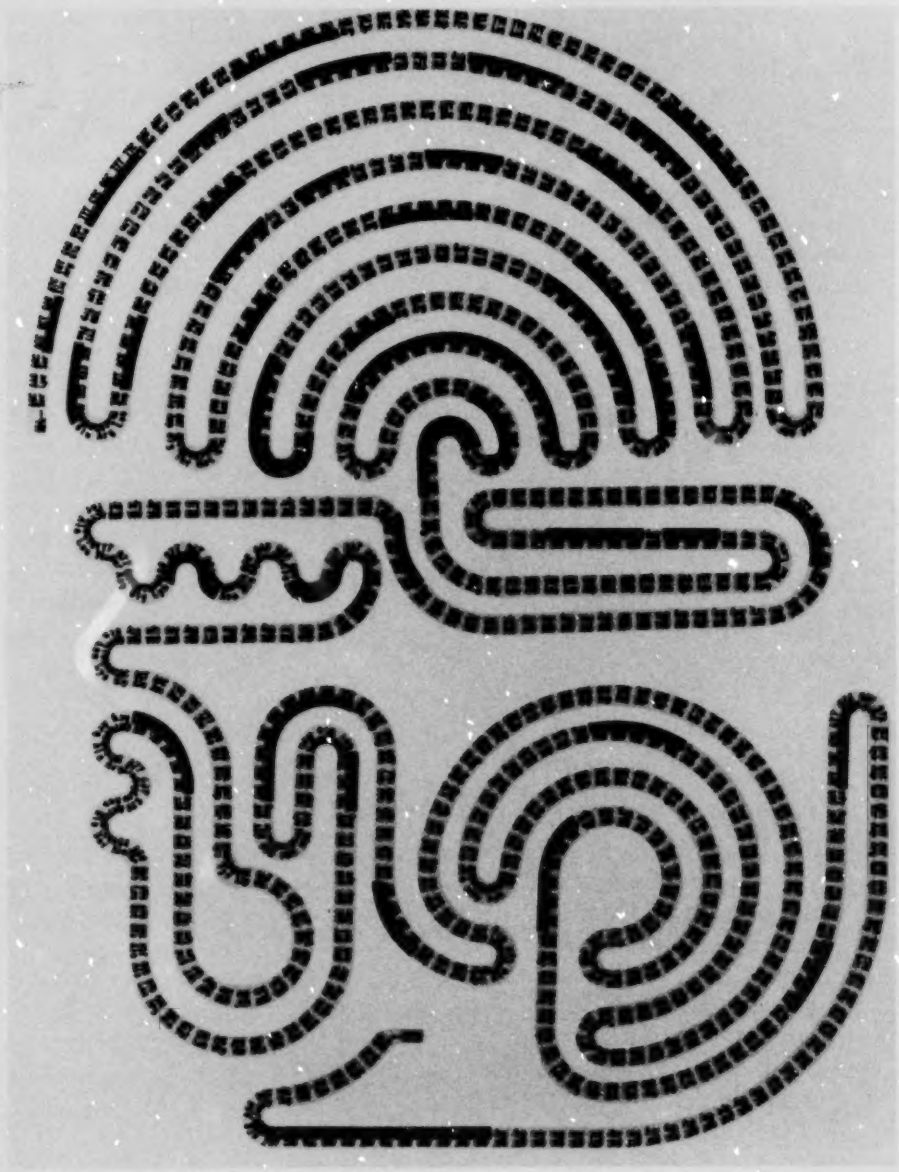
Molecular Biology and the Degree of Relationship Very recent studies in molecular biology have independently confirmed the judgments of paleontologists and classical biologists about relationships among lineages and the order in which species appeared within lineages. They have also provided detailed information about the mechanisms of biological evolution.

DNA (deoxyribonucleic acid), the hereditary material within all cells, and the proteins encoded by genes in the DNA both offer extensive information about the ancestry of organisms. Analysis of such information has made it possible to reconstruct evolutionary events that were previously unknown and to confirm and date events already surmised but not precisely dated. The precision whereby evolutionary events can be thus reconstructed is one reason why the evidence from molecular biology is so compelling.

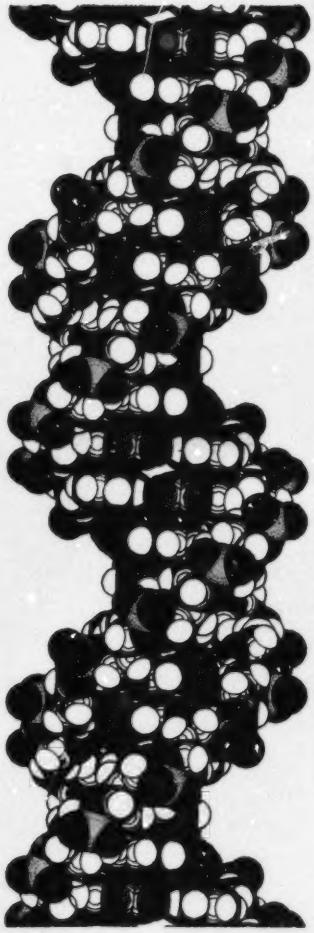
In unveiling the universality of the chemical basis of heredity, molecular biology has profoundly affirmed common ancestry. In all organisms—bacteria, plants, and animals, including humans—the hereditary information is encoded in DNA, which is in all instances made up of the same

four subunits called nucleotides. The genetic code by which the information contained in the nuclear DNA is used to form proteins is essentially the same in all organisms. Proteins in all organisms are invariably composed of the same 20 amino acids, all having a "left-handed" configuration, although there are amino acids in nature with both "right-" and "left-handed" configurations. The metabolic pathways through which the most diversified organisms produce energy and manufacture cell components are also essentially the same.

This unity reveals the genetic continuity of living organisms, thereby giving independent confirmation of descent from a common ancestry. There is no other way consistent with the laws of nature and probability to account for such uniformity. The genetic code may serve as an example. In general, each of the 64 possible sequences of three of the four nucleo-



The genetic code consists of sequences of nucleotide triplets (e.g., TTG), which are translated into sequences of amino acids such as leucine. In this illustration the amino acid sequence of an aminoacyl-tRNA (transfer ribonucleic acid) synthetase enzyme is translated from, and shown next to, the nucleotide sequence of DNA (deoxyribonucleic acid), which constitutes its gene. The darker blue shaded areas of the enzyme indicate those regions that have been checked by mass spectrometric analyses.



In this computer-generated diagram of DNA, phosphorus is yellow, nitrogen is blue, oxygen is red, and hydrogen is white.

tides in the nuclear DNA has the same meaning in all organisms. The significance of this can be seen by comparing the genetic code to human languages. Many different languages have evolved, each using certain combinations of symbols and sounds to convey a specific meaning. If similar combinations of symbols and sounds are used to express the same meaning in different languages, we infer that the languages involved had a common source. The genetic code is a universal language, implying a single source.

Consider a comparison between two books of similar length. Let us say that closer examination reveals that the two books are identical page by page and word by word, except that an occasional word, say one in a hundred, is different. It is highly improbable that the two books were written independently: either one book was copied from the other or both were copied from a third source. Now, if each nucleotide in human DNA is represented by one letter, the complete sequence of nucleotides would require over a million pages. When the pages in the human genetic book are compared with those of diverse organisms, correspondence in the sequence of letters gives unmistakable evidence of common origin. Occasional changes provide information about particular species, just as all copies of a specific edition of a book can be identified by common changes.

Thus molecular biology validates the already impressive evidence that all living organisms, from bacteria to humans, are ultimately descended from common ancestors (Dobzhansky *et al.*, 1977). Since evolutionists of earlier times knew nothing about molecular biology, discoveries resulting from studies in this relatively new field of science provide independent and unanticipated reinforcement of their theories.

But the evidence for evolution from molecular biology goes further. The *degree* of similarity in the sequence of nucleotides in DNA (or of amino acids in proteins) can now be precisely quantified. For example, the protein cytochrome-c in humans and chimpanzees consists of the same 104 amino acids in exactly the same order, whereas that of rhesus monkeys differs from them by one amino acid, that of horses by 11 amino acids, and that of the tuna by 21 amino acids. The extent of deviation corresponds to the time interval since fish, mammals, and human ancestors appeared in the geological record, i.e., the degree of divergence reflects the time that has passed since the respective lineages had a common ancestry. Thus, inferences from paleontology, comparative anatomy, and other disciplines as to the evolutionary history of organisms can be tested by examining the sequences of nucleotides in the DNA or the sequences of amino acids in protein. The potential power of such tests is overwhelming. Each of the thousands of genes and proteins provides an independent test of evolutionary history.

Only a few of the countless possible tests have been performed, of course. But of the many hundreds that have been conducted, none has provided evidence contrary to the concept of evolution. Instead, molecular biology confirms the idea of common descent in every aspect.

Evolution pervades all biological phenomena. To ignore that it occurred or to classify it as a form of dogma is to deprive the student of the most fundamental organizational concept in the biological sciences. No other biological concept has been more extensively tested and more thoroughly corroborated than the evolutionary history of organisms. The *mechanisms* by which evolution occurred, however, are not agreed upon in detail. They remain an area for continuing research, discussion, and discovery.

Mechanisms of Evolution Students of evolutionary biology seek not only to reconstruct the evolutionary history of organisms but also to discover the specific mechanisms that account for evolutionary change. Research on this subject is currently so lively that we can include in this brief document only some well-tested and widely agreed upon generalities.

Darwin proposed that evolution could be explained by hereditary variation followed by natural selection. His original hypothesis has undergone extensive modification and expansion, but the central concepts stand firm. Mendelian genetics and molecular biology were unknown to Darwin, but studies in these fields have explained the occurrence of hereditary variations essential to Darwin's ideas. Genetic variations result from changes in DNA structure, whether by mutation, recombination, or some other yet incompletely understood mechanism. Such changes in DNA can now be physically observed and numerically quantified in many favorable circumstances (Ayala and Valentine, 1979).

There is still much to be learned from new experiments and observations. Meanwhile, biologists and paleontologists are debating the relative importance of the various mechanisms in order to devise questions that will produce the most meaningful inquiries into the methods and rates of evolution.

One point concerning mechanisms deserves emphasis. Mutations and other variations arise by chance. They do not necessarily equip the organism with better means for surviving in its environment. But if a gene variant improves adaptation (for example, by allowing an organism to make use of an available nutrient or to escape predators more effectively), the organisms carrying that gene are more likely to survive and reproduce than those without it. Thus, much as Darwin proposed, natural selection is the process that gives direction to evolution and makes it more than the product of chance. Natural selection accounts for the apparent design of organisms as well as their imperfections. Adaptations, whether expressed as simple metabolic reactions or as a complicated organ like the human eye, are considered by the overwhelming majority of biologists to be the result of natural selection. For this reason, the theory of natural selection is called upon to explain the observable evidence for biological evolution.

Human Evolution

Studies in evolutionary biology have led to the conclusion that mankind arose from ancestral primates. This association was hotly debated among scientists in Darwin's day, before molecular biology and the discovery of the now abundant connecting links. Today, however, there is no significant scientific doubt about the close evolutionary relationships among all primates or between apes and humans (Andrews and Cronin, 1982; Simons, 1980, 1981). The "missing links" that troubled Darwin and his followers are no longer missing. Today, not one but many such connecting links, intermediate between various branches of the primate family tree, have been found as fossils. These linking fossils are intermediate in form and occur in geological deposits of intermediate

age. They thus document the time and rate at which primate and human evolution occurred.

The possibility of error in determining ages has been reduced by new methods based on measurements of reversals in the earth's magnetic field in ancient rocks. Furthermore, fossils continue to be found with great frequency. The combination of information from stratigraphy, fossils, and dating techniques and findings from studies in molecular biology has enabled scientists to develop the following scheme of human evolution. The human line separated from that of the apes approximately 5 million years ago. About 4 million years ago, our ancestors were already bipedal but had brains no larger than those of the contemporary apes. Within 2 million years after that, these small-brained bipeds were making stone tools. In the next half million years, the brain doubled in size and the stone tools became much more complex. Change was very slow until people anatomically similar to ourselves had evolved. Then in a few thousand years, humans reached Australia, the Arctic, and the New World. Tools were improved, and boats, bows, and sleds were invented. This revolution was accompanied by the development of agriculture and shortly thereafter, from an evolutionary point of view, the complex social and industrial world we know today.

From the time of our earliest ancestors onward, there were successive and regular increases in average brain volume and body size, coupled in later stages with a progressive reduction in the thickness of the brain case, the protrusion of brow ridges, and the size of cheek teeth. These changes occurred through a succession of well-documented intermediate forms or species. Finally, approximately 50,000 years ago, *Homo sapiens sapiens*—the oldest human being of morphologically modern character—appeared. This appearance of fully developed modern man close to 50,000 years ago is, of course, inconsistent with the creationist view that the earth is perhaps only 10,000 years old or less.

The evolution of the skull was marked by two major characteristics: the cranium (and brain) became larger and the face smaller. *Homo erectus* marks the approximate midpoint in this transition from ancient apelike creatures to modern human beings.

These conclusions from comparative anatomy, stratigraphy, dating techniques, and paleoanthropology are backed up by findings from studies in molecular biology. A 99 percent similarity is found between the DNA of human beings and the DNA of chimpanzees. Such studies link humans, the chimpanzee, and the gorilla together in the same biological family.

The Origin of Life

Scientific research on the origin of life is in an exploratory phase, and all its conclusions are tentative. We know that the organisms that lived on earth 2 billion or more years ago were simple microbial forms. There is even some evidence that life might already have existed when the first known solid crust formed on earth, almost 4 billion years ago. The geological record indicates that liquid water, other chemicals, and a suitable atmosphere for prebiotic chemical activity were present on earth more than 3.8 billion years ago. Earliest life was unicellular or noncellular, existed in the absence of oxygen, and may have been incapable of producing its own nutrients from solar or chemical energy. Experimental results and astronomical observations are consistent with the idea that the steps required to link and set into operation the essential components of a living cell could have occurred under conditions prevailing on the primitive earth. They could not occur now because of the destructive effects of today's abundant molecular oxygen, not only on simple unprotected living systems but also on the intermediate products that might have generated the component molecules of such systems.

Experiments conducted under plausible primitive-earth conditions have resulted in the production of amino acids, large protein-like molecules made from long chains of amino acids, the nucleotide components of DNA, and DNA-like chains of these nucleotides. Many biologically interesting molecules have also been detected by astronomers using radiotelescopes. We can, therefore, explain how the early oxygen-free earth provided a hospitable site for the accumulation of molecules suitable for the construction of living systems. Such molecules could have been formed as a result of chemical reactions on the earth's surface, or they could have arrived in carbonaceous meteorites. Perhaps both sources are responsible for their presence.

In 1953, Stanley Miller (shown above) and Harold Urey used an electrical discharge apparatus of the type seen in this 1975 photograph to accomplish the first laboratory synthesis of amino acids in a simulated primitive earth environment.

Once the starting materials such as amino acids and nucleotides have been formed, larger molecules can then be made experimentally by removing water through a process called dehydration condensation. Amino acids join to form proteins, and nucleotides join to form nucleic acids. Even DNA molecules have been synthesized from purified components taken from the laboratory shelf.

For those who are studying aspects of the origin of life, the question no longer seems to be whether life could have originated by chemical processes involving nonbiological components but, rather, what pathway might have been followed. The data accumulated thus far imply selective processes. Prebiological chemical evolution is seen as a trial-and-error process leading to the success of one or more systems built from the many possible chemical components. The system that evolved with the capa-

bility of self-replication and mutation led to what we now define as a living system.

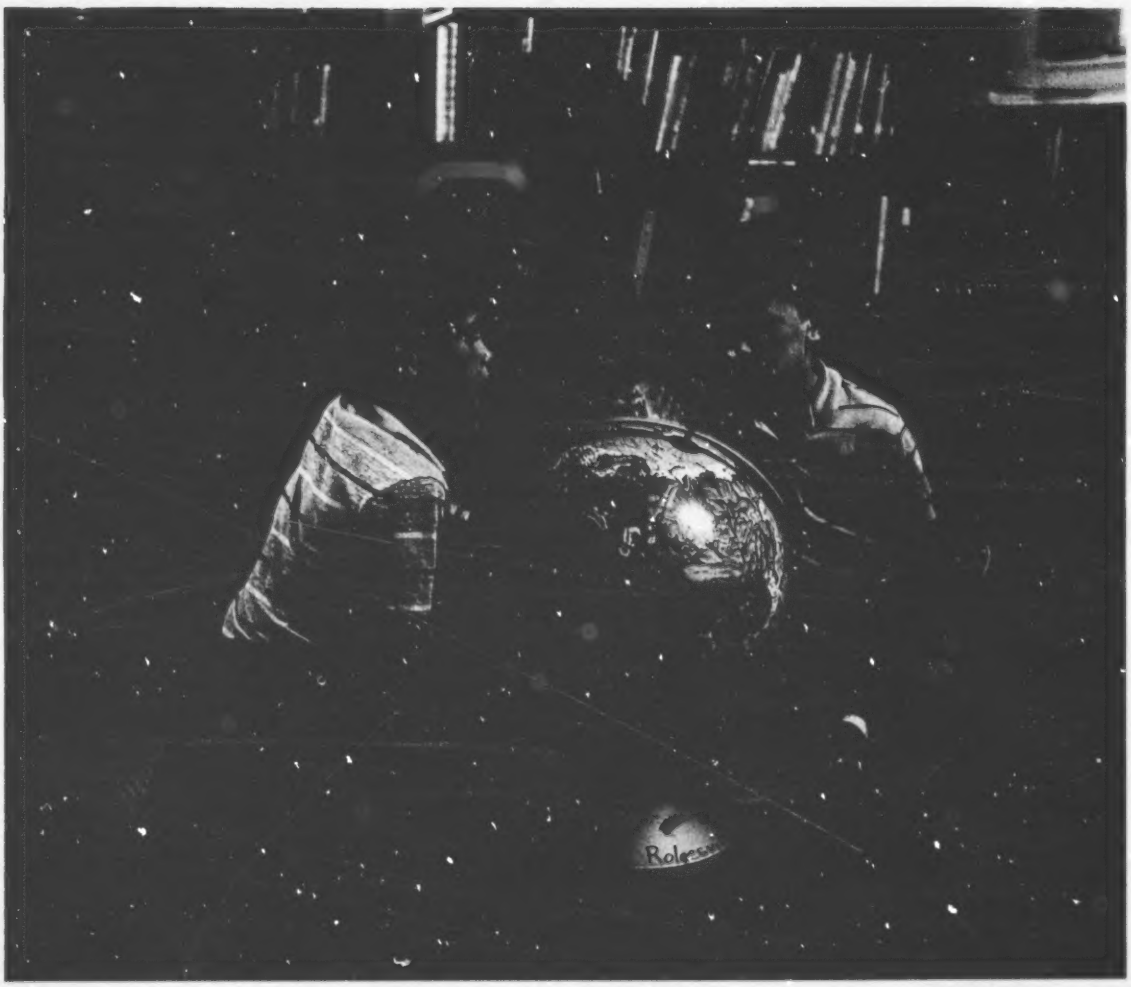
Will we ever be able to identify the path of chemical evolution that succeeded in initiating life as we know it? This question may be unanswerable. Even if a living cell were to be made in the laboratory, that event would not prove that nature followed the same pathway billions of years ago. Still, the history of science shows that seemingly intractable problems may become amenable to solution as a result of advances in theory or instrumentation or the fortuitous discovery of new facts.

Conclusion

Scientists, like many others, are touched with awe at the order and complexity of nature. Religion provides one way for human beings to be comfortable with these marvels. However, the goal of science is to seek naturalistic explanations for phenomena—and the origins of life, the earth, and the universe are, to scientists, such phenomena—within the framework of natural laws and principles and the operational rule of testability.

It is, therefore, our unequivocal conclusion that creationism, with its accounts of the origin of life by supernatural means, is not science. It subordinates evidence to statements based on authority and revelation. Its documentation is almost entirely limited to the special publications of its advocates. And its central hypothesis is not subject to change in light of new data or demonstration of error. Moreover, when the evidence for creationism has been subjected to the tests of the scientific method, it has been found invalid.

No body of beliefs that has its origin in doctrinal material rather than scientific observation should be admissible as science in any science course. Incorporating the teaching of such doctrines into a science curriculum stifles the development of critical thinking patterns in the developing mind and seriously compromises the best interests of public education. This could eventually hamper the advancement of science and technology as students take their places as leaders of future generations.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